Satellites and Sensors: Satellite Missions Impacting the Estimation of Solar Irradiance

Paul Stackhouse
NASA Langley Research Center
Hampton Virginia

In this talk, an overview of present and future satellite missions is presented with the perspective of improving the estimation of solar irradiance at the earth's surface. To properly introduce the discussion, the uncertainties in the estimation of solar irradiance at the surface are discussed briefly. These uncertainties range from the calibration of the instrumentation, to spatial/temporal problems, uncertainties in the radiative properties of clouds, aerosols, and surface. Then several planned and proposed satellite missions are discussed showing how some of these uncertainties should be addressed with the advances in satellite technology. Although, some geosynchronous platforms will be mentioned, emphasis will be given to polar orbiting missions since geosynchronous missions are discussed in the presentations following this one.

In the near future, the satellite missions of importance to the solar energy community are the called Tropical Rainfall Measurement Mission (TRMM) and the Earth Observing System (EOS) satellites those sponsored by NASA's Earth System Enterprise EOS-AM1 and EOS-PM1. These satellites contain multispectral imagers, multi-angle cameras, broadband multi-angle radiometers, and spectrometers to infer atmosphere, cloud, aerosol, and surface properties. The CERES (Clouds and Earth's Radiant System) instrument package, which is present on all three platforms, provides multi-angular views of broadband solar and thermal infrared radiance that are inverted to estimate top-of-atmosphere (TOA) radiative fluxes constraining the radiant flux of the atmospheric column. Temporal overlap between at least two and possibly all satellites will provide the best temporal and spatial sampling of these fluxes to date. Several solar irradiance products are planned from the CERES Surface and Atmospheric Radiation Budget (SARB) group at 1 Degree resolution for scientific research. Potentially, these data will represent a very accurate source of solar irradiance estimates for solar energy assessment projects.

Besides the EOS missions several other missions are outlined that will lead to advances of our understanding of clouds and aerosols. Some of these missions are to be flown in conjunction with the EOS-PM platform and others are on completely separate platforms many to be flown by various space agencies around the world. Most of these missions do not plan solar insolation products, but the scientific knowledge gained may have a profound effect on the improvement of current techniques. Finally, I summarize the planned launches and mission lifetimes and surmise when these data might be available to the solar energy community at large.

Satellites and Sensors

Satellite Missions Impacting the Estimation of Solar Irradiance

Paul Stackhouse Jr., NASA Langley Research Center

Satellite Data Analysis Center / NASA Langley Research Center

Presentation Outline

- Uncertainties in the estimation of solar insolation from space
- Current satellite platforms used for solar insolation estimation
- Near term/future satellite platforms to improve past/future solar insolation estimates

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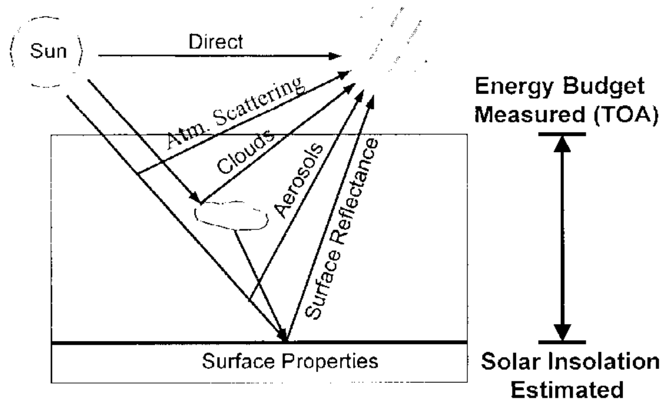
Solar Energy Sources to Spacecraft



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Cloud Radiative Property Issues

- **Cloud Composition**
  - phase (ice or water, refractive indices)
  - particle distribution, shape, and density (single-scattering properties: extinction, absorption, phase function)
- **Cloud Appearance**
  - cloud fraction (view angle dependence)
  - height (effects phase and emittance properties)
  - thickness/shape (vertical development, total mass)
  - multi-layering (scattering between cloud layers)
  - heterogeneity (horizontal propagation of energy)

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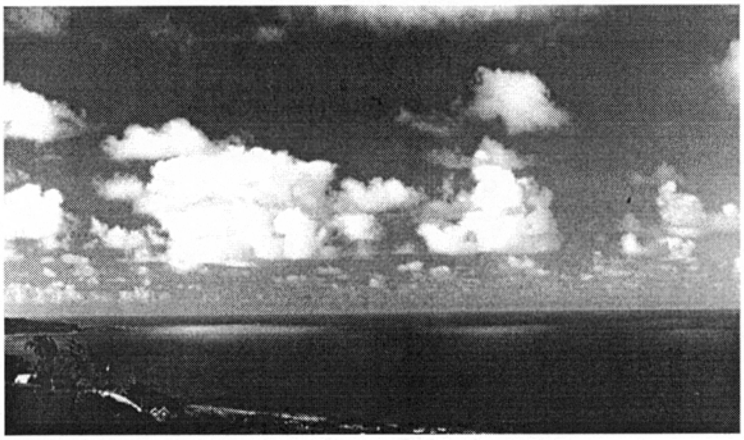
Cloud Inhomogeneity

Effects both surface and satellite observations



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Aerosol Radiative Property Issues

- **Aerosol Composition**
  - chemical composition (sulfur, carbon, quartz: refractive indices)
  - particle distribution, shape, and density (normal or bimodal: single-scattering properties)
- **Aerosol Structure**
  - height (volcanic, industrial, biomass burning, dust)
  - thickness (total mass, profile)
  - spatial/temporal distribution

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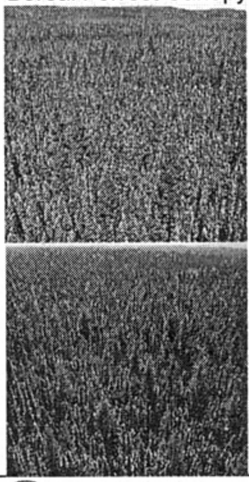
Surface Radiative Properties Issues

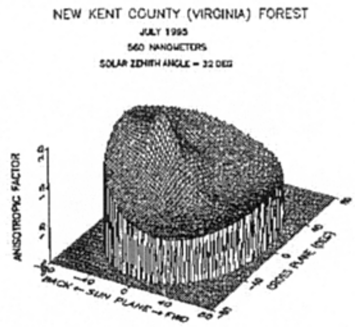
Boreal Forrest Canopy



Back Plane
(sun to back)

Forward Plane
(sun in front)

Reflected radiance depends on both the angular distribution of the incident solar energy and a surface's reflectance properties in the direction of the measurement.

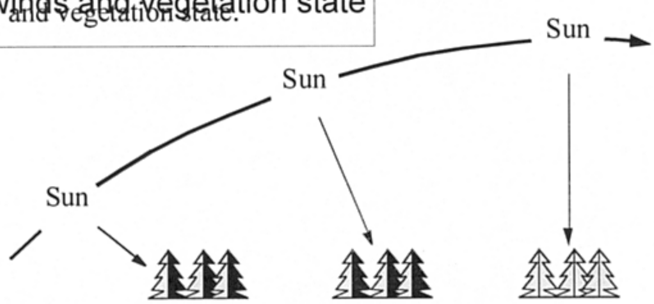


Surface Radiative Property Issues

Surface Reflectance Depends upon:

- Angle of Sun (shadowing and canopy texture)
- Viewing angle (relative to solar plane)
- Winds and vegetation state

and vegetation state.



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Past/Current Satellite Missions

Sensor/Agency	Launch Date	Spectral Channels l, mm	Comments
AVHRR/NOAA	since 1979	4 bands [0.64] [0.83] [3.75] [11.5]	Nadir viewing scanner, operational
TM-Landsat/NASA	since 1982	6 bands [0.47-2.20]	Nadir viewing scanner
MSS-Landsat/NASA	since 1971	4 bands [0.55-0.90]	Nadir viewing scanner
VISSR-GOES/NOAA	since 1975	1 band [0.66]	Geostationary, operational
SAGE I, II/NASA	since 1979	7 bands [0.38-1.08]	Solar occultation
TOMS-Nimbus 7 /NASA	since 1978	2 bands [0.34-0.38]	Nadir viewing scanner
OCTS-ADEOS/ NASDA	1996-97	9 bands [0.41-o.86] and 3.9	Nadir viewing scanner

Source: NASA RA NRA-97-MTPE-16

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Past/Current Satellite Missions

Sensor/Agency	Launch Date	Spectral Channels l, mm	Comments
POLDER-ADEOS/ CNES-NASDA	1996-97	8 bands [0.44-0.91] 3 polarized bands multiview angles	Nadir viewing scanner
ERBE-ERBS & NOAA/ NASA	1984/1998	3 broad channels [0.3 - 50] [0.3 - 5] [8 - 12]	Low resolution nadir scanner
SeaWiFS-SeaStar/ NASA	1997	8 bands [0.41-0.86]	Nadir viewing scanner
LITE/NASA	1993	3 laser wavelengths [1.06] [0.53] [0.35]	Nadir viewing lidar on the Space Shuttle

Source: NASA RA NRA-97-MTPE-16

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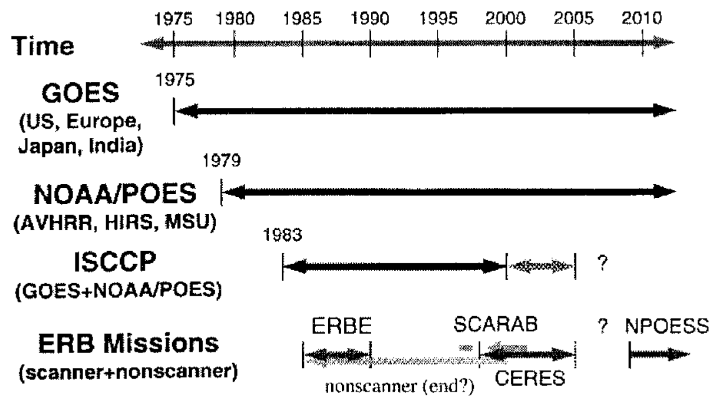
Time Line of Satellite Missions Useful For Solar Insolation Estimates



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Sample Future Missions: Clouds, Aerosols, Surface

Sensor/Agency	Launch Date	Spectral Channels # [micrometers]	Comments
CERES-TRMM, EOS AM1, & PM1/NASA	Nov 97/ Jul 99/ Dec 00	3 broad channels [0.3 – 50; 0.3 – 5; 8 – 12]	20 km resolution, azimuthal & cross-track scanning
MODIS-EOS AM1 & PM1/NASA	Jul 99/ Dec 00	12 bands [.41 – 2.10, 3.96]	Nadir viewing scanner
MISR-EOS AM1 & PM1/NASA	Jul 99/ Dec 00	4 bands [0.47 – 2.10]	9 view angles
MERIS-ENVISAT/ESA	May 00	15 bands [0.4 – 1.02]	Multiple angle viewing
AATSR-ENVISAT/ESA	May 00	7 bands [0.55 – 12.0]	1 km, Two angle view
GLI-ADEOS II/NASDA	1999	12 band [0.41- 2.10]	Nadir viewing scanner
POLDER-ADEOS II/ NASDA	1999	8 bands [.44 -.91], 3 polarized	Nadir viewing scanner and multiview
SAGE III-Meteor/NASA	Jul 99	9 bands [0.29 - 1.55]	Solar occultation

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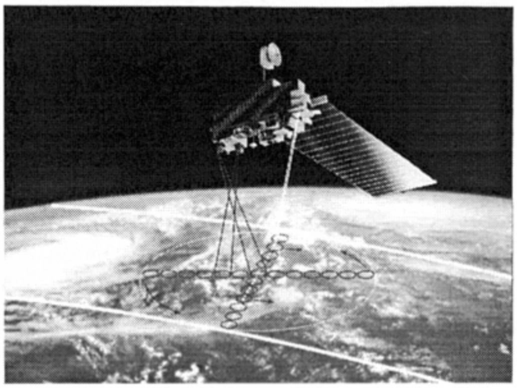
TRMM and EOS Satellite Instrumentation

- **Tropical Rainfall Measurement Mission**
  - Clouds and the Earth Radiant Energy System (CERES)
  - Visible InfraRed Scanner (VIRS)
  - Precipitation/Lightening instrumentation
- **EOS-AM**
  - Moderate Resolution Imaging Spectroradiometer (MODIS)
  - Advanced Spaceborne Thermal Emission Radiometer (ASTER)
  - Multi-angle Imaging Spectroradiometer (MISR)
  - Measurement of Pollution in the Troposphere (MOPITT)
  - Clouds and the Earth Radiant Energy System (CERES)
- **EOS-PM**
  - Clouds and the Earth Radiant Energy System (CERES)
  - Moderate Resolution Imaging Spectroradiometer (MODIS)
  - Advanced Microwave Scanning Radiometer-EOS (AMSR-E)
  - Advanced Microwave Sounding Unit (ASMU)
  - Atmospheric Infrared Sounder (AIRS)

Clouds and the Earth Radiant Energy System (CERES)

- **Provided by NASA Langley Research Center and built by TRW.**
- **Long-term measurements of Earth's radiation budget through observations of short and longwave radiation.**
- **Broadband scanning thermistor bolometer package with 20 km resolution. Two identical scanners carried to operate in x-track and biaxial scan modes. Each scanner has three channels: shortwave infrared for reflected sunlight, longwave for Earth-emitted thermal IR, and total channel.**



(Source: Bordi *et al.*, 48th Congress of the International Astronautical Federation, Torina, Italy, 6-10 October 1997)

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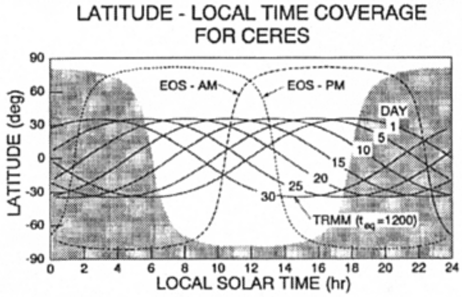
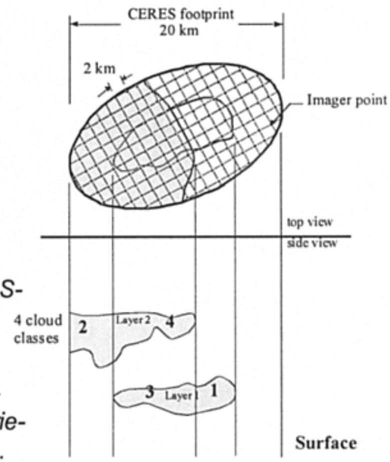
CERES Temporal and Spatial Sampling



The tri-satellite configuration with TRMM, EOS-AM and EOS-PM result in the sampling of all local times in a month between 35° N and S.

The CERES based surface fluxes at the foot-print level are computed using convolved retrie-vals of cloud, aerosol, and surface properties.



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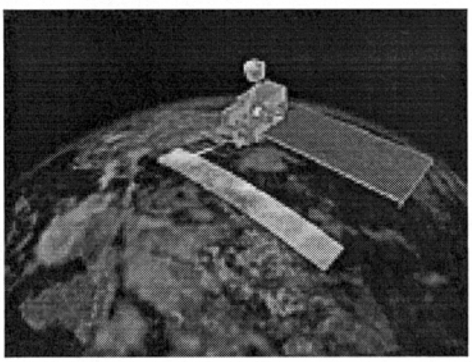
Moderate Resolution Imaging Spectroradiometer (MODIS)

- **Provided by NASA Goddard Space Flight Center and built by Hughes SBRS.**
- **Measurement of comprehensive global biological and geophysical processes including: surface temperature (land and sea), ocean color, global vegetation and deforestation, clouds and aerosols, and snow cover.**
- **Cross-track scanning imaging radiometer with 36 bands from visible to thermal IR and spatial resolutions of 250m, 500m, and 1km at nadir. 2330 km swath for global coverage in 2 days.**
- **Provides imager data requir-ed for CERES surface fluxes**



(Source: Bordi *et al.*, 48th Congress of the International Astronautical Federation, Torina, Italy, 6-10 October 1997)

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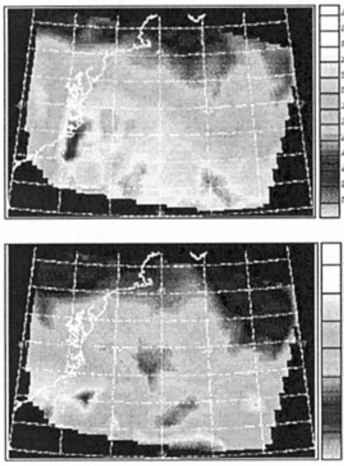
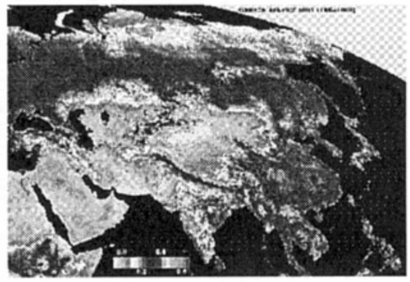
Sample MODIS Data Products



MODIS Atmospheric Profiles.



Growing Season Average NDVI of Asia Derived from the Advanced Very High Resolution (AVHRR) Pathfinder Data Set. Monthly NDVI was calculated as the average of three 10-day composites. The monthly values were further averaged over the 9-year period of record before Mount Pinotubo eruption (1982-1990) to obtain long-term average monthly NDVI values.

(Source: Bordi *et al.*, 48th Congress of the International Astronautical Federation, Torina, Italy, 6-10 October 1997)

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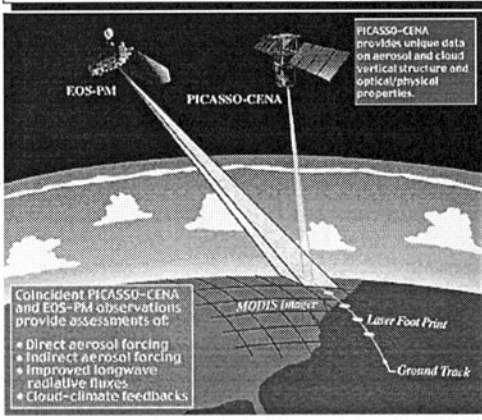
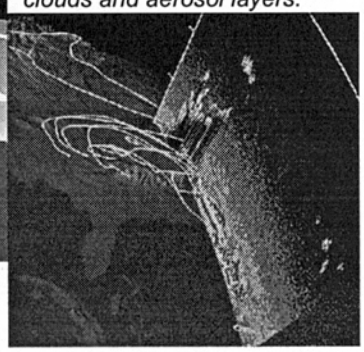
NASA Special Missions: PICASSO-CENA



Vertical Lidar backscatter profiles from the space shuttle LITE experiment. Yellow lines trace trajectories of air into clouds and aerosol layers.



Lidar measurements in conjunction with the MODIS imager improves cloud and aerosol radiative properties for solar flux estimates.

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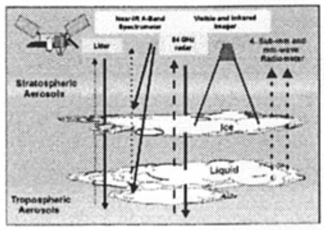
NASA Special Missions: CloudSat

MEASUREMENT OBJECTIVES:

- PROFILE THE VERTICAL STRUCTURE OF CLOUDS
- MEET MAJOR SHORTFALLS IN CLOUD AND AEROSOL OBSERVATIONS, USING ACTIVE AND PASSIVE INSTRUMENTS
- ASSESS THE PERFORMANCE OF PASSIVE INSTRUMENT SUITES ON OTHER SATELLITE PLATFORMS; VALIDATE AND IMPROVE THEIR MULTILAYER CLOUD AND AEROSOL RETRIEVALS

MISSION PERFORMANCE CAPABILITIES:

- Cloud height /base
  - Radar: 250m - 500 m resolution
  - Lidar: < 100 m resolution
- Cloud properties
  - Two-dimensional profile of optical depth, ice content, liquid content, particle size
- Visibility
  - Along-track slant range visibility
- Precipitation occurrence and amount
- Sub-visual cirrus
  - Optical depth and altitude.
- Aerosols
  - Optical depth and layer thickness



Spacecraft #1 — Spacecraft #2 Icesat or PICASSO

Formation fly

Sensor Specifications:

1. **RADAR:** 94 GHz, sensitivity -30 to -36 dBZ
2. **LIDAR:** 532/1064 nm, sensitivity ~1E-6/m/s
3. **THERMAL IR CAMERA:** 2 channel radiometer
4. **VIS IMAGER/SPECTROMETER:** with high spectral resolution (A-band) spectrometer for detection of thinnest cirrus/aerosols

3 & 4 common to both spacecraft:

Source: Dr. Graeme Stephens, Colorado State Univ.

Atmosphere

- **Surface/Atmospheric State**
  - **Surface State: Land and Ocean**
    - MODIS, MISR, ASTER, POLDER, AM SR, MERIS, GLI, AATSR
    - TOPEX, NSCAT, Precip and Surface Radars
  - **Atmospheric State: Temperature/Humidity:**
    - AIRS/AMSU/MHB + 4-D Assimilation: 2000-2005/9, MIPAS
    - NPOESS + 4-D Assimilation: 2005/9 and beyond
    - Geostationary + 4-D: *Future TBD*
    - DIAL lidar for moisture vertical profiles + 4-D: *Future TBD*
  - **Atmospheric State: Winds:**
    - T(z) + 4-D
    - Geostationary moisture field winds + 4-D: *Future TBD*
    - Lidar winds+ 4-D: *Future TBD*

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Cloud and Aerosol Properties

- **Aerosol Properties:**
  - MODIS, MISR, POLDER, MERIS, GLI, AATSR
  - PICASSO lidar/A-band
- **Cloud Properties:**
  - MODIS, MERIS, GLI, AMSR
  - PICASSO lidar/A-band: (most cloud layers)
  - CloudSat cloud radar (all but thinnest cloud layers): *Future TBD*
  - Submm/Far-Infrared for Ice Water Path/Ice Particle Size: *Future TBD*

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Global Radiative Energy Fluxes

- **TOA Radiative Fluxes:**
  - CERES + MODIS
  - *CERES beyond 2005: Future TBD*
- **Surface/Atmosphere Radiative Fluxes:**
  - CERES + MODIS TOA Fluxes (constraint)
  - PICASSO + CLOUDSAT cloud/aerosol vertical properties
  - MODIS, MERIS, GLI cloud/aerosol area properties
  - MODIS/MISR/AMSR Surface Properties
  - AIRS/AMSU/MHB + 4-D Assimilation => T(z),q(z)

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